Chapter 9

CLOUDS AND PRECIPITATION

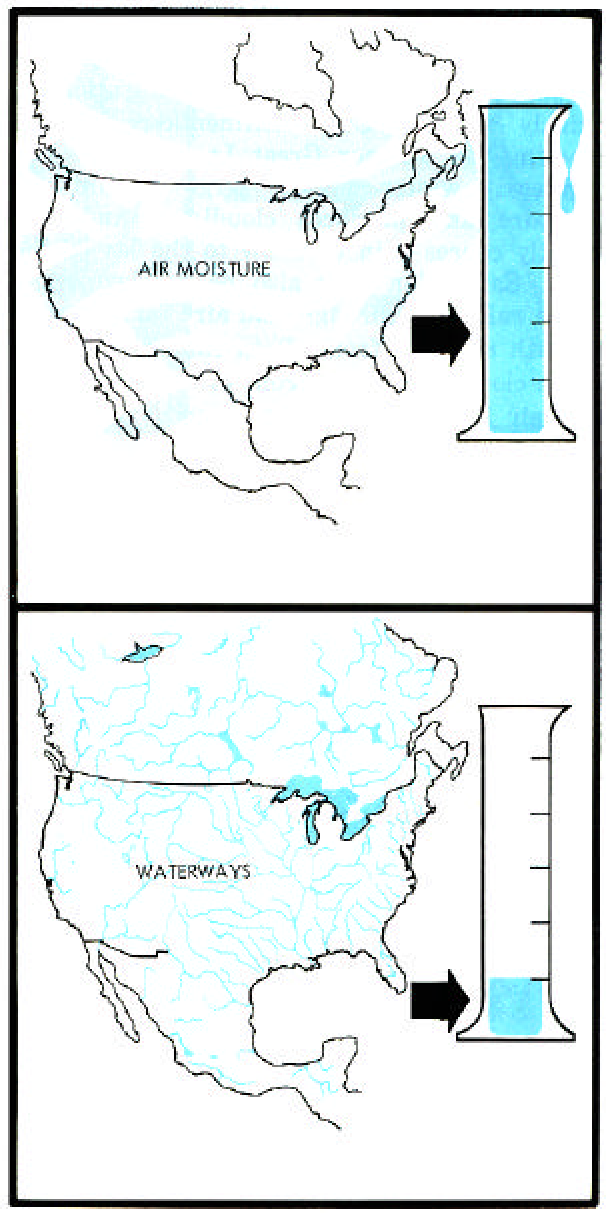
Fire weather is usually fair weather. Clouds, fog, and precipitation do not predominate during the fire season. The appearance of clouds during the fire season may have good portent or bad. Overcast skies shade the surface and thus temper forest flammability. This is good from the wildfire standpoint, but may preclude the use of prescribed fire for useful purposes. Some clouds develop into full-blown thunderstorms with fire-starting potential and often disastrous effects on fire behavior.

The amount of precipitation and its seasonal distribution are important factors in controlling the beginning, ending, and severity of local fire seasons. Prolonged periods with lack of clouds and precipitation set the stage for severe burning conditions by increasing the availability of dead fuel and depleting soil moisture necessary for the normal physiological functions of living plants. Severe burning conditions are not erased easily. Extremely dry forest fuels may undergo superficial moistening by rain in the forenoon, but may dry out quickly and become flammable again during the afternoon.

CLOUDS AND PRECIPITATION

Clouds consist of minute water droplets, ice crystals, or a mixture of the two in sufficient quantities to make the mass discernible. Some clouds are pretty, others are dull, and some are foreboding. But we need to look beyond these aesthetic qualities. Clouds are visible evidence of atmospheric moisture and atmospheric motion. Those that indicate instability may serve as a warning to the fire-control man. Some produce precipitation and become an ally to the firefighter. We must look into the processes by which clouds are formed and precipitation is produced in order to understand the meaning and portent of clouds as they relate to fire weather. We will see how clouds are classified and named, and what kinds of precipitation certain types of clouds produce.

The total amount of water vapor in the atmosphere is very large. It has been estimated that the amount carried across the land by air currents is more than six times the amount of water carried by all our rivers. One inch of rainfall over an acre weighs about 113 tons. Over an area the size of Oregon, 1 inch of rain is equivalent to nearly 8 billion tons of water. All of this water comes from condensation of vapor in the atmosphere. For each ton of water that condenses, almost 2 million B.t.u.'s of latent heat is released to the atmosphere. It becomes obvious that tremendous quantities of water and energy are involved in the formation of clouds and precipitation.



The total amount of water vapor that flows across the land on air currents originating over water is estimated to be more than six times the water carried by all our rivers.

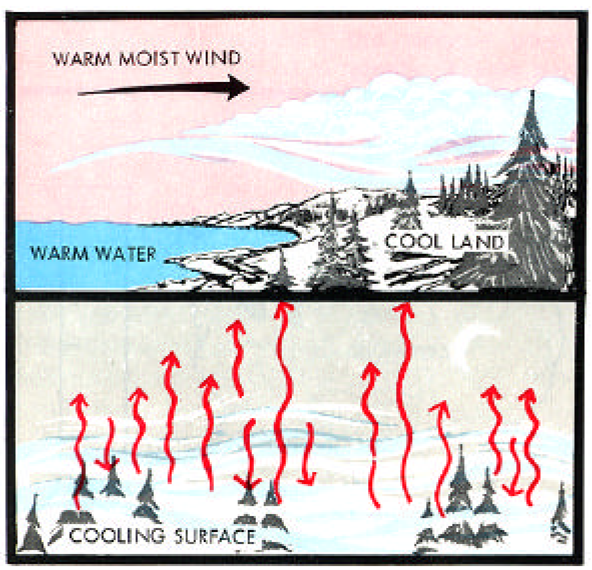
In order for clouds to form and precipitation to develop, the atmosphere must be saturated with moisture. In chapter 3 we learned that at saturation the atmospheric vapor pressure is equal to the saturation vapor pressure at the existing temperature and pressure. There are two principal ways in which the atmospheric vapor pressure and saturation vapor pressure attain the same value to produce 100 percent relative humidity, or saturation. These are through the addition of moisture to the air, or, more importantly, through the lowering of air temperature.

As cold air passes over warm water, rapid evaporation takes place, and saturation is quickly reached. Cold continental polar air crossing the warmer Great Lakes in the fall and early winter gathers large amounts of moisture and produces cloudiness and frequently causes rain or snow to the lee of the lakes. Saturation may also be reached when warm rain falls through cold air; for example, beneath a warm front. Rain falling from the warm clouds above the front evaporates in the cold air beneath and forms scud clouds. Contrails made by high-flying aircraft are a type of cloud formed by the addition of moisture from the plane's exhaust.

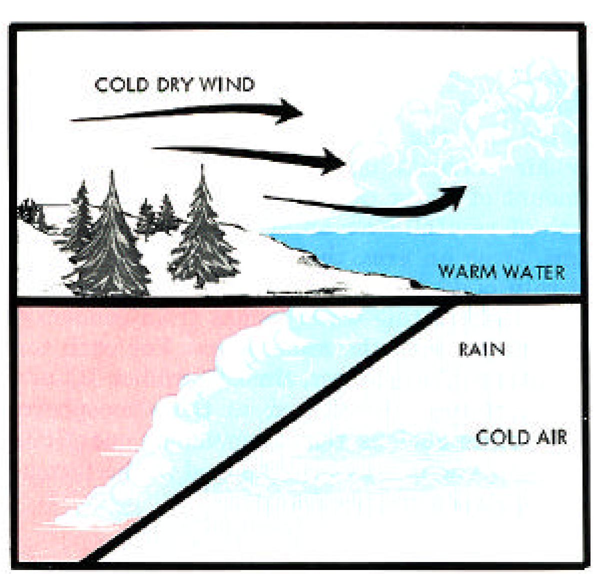
The more important method of reaching saturation, by lowering air temperature, is accomplished in several ways. Warm, moist air may be cooled to its dew point by passing over a cold surface. The cooling takes place near the surface so that, with light wind conditions, fog is formed. If the winds are strong, however, they will cause mixing of the cooled air, and clouds will form several hundred or even a thousand or more feet above the surface.

Lifting of air, and the resultant adiabatic expansion, is the most important cooling method. The lifting may be accomplished by thermal, orographic, or frontal action. It produces most of the clouds and precipitation.

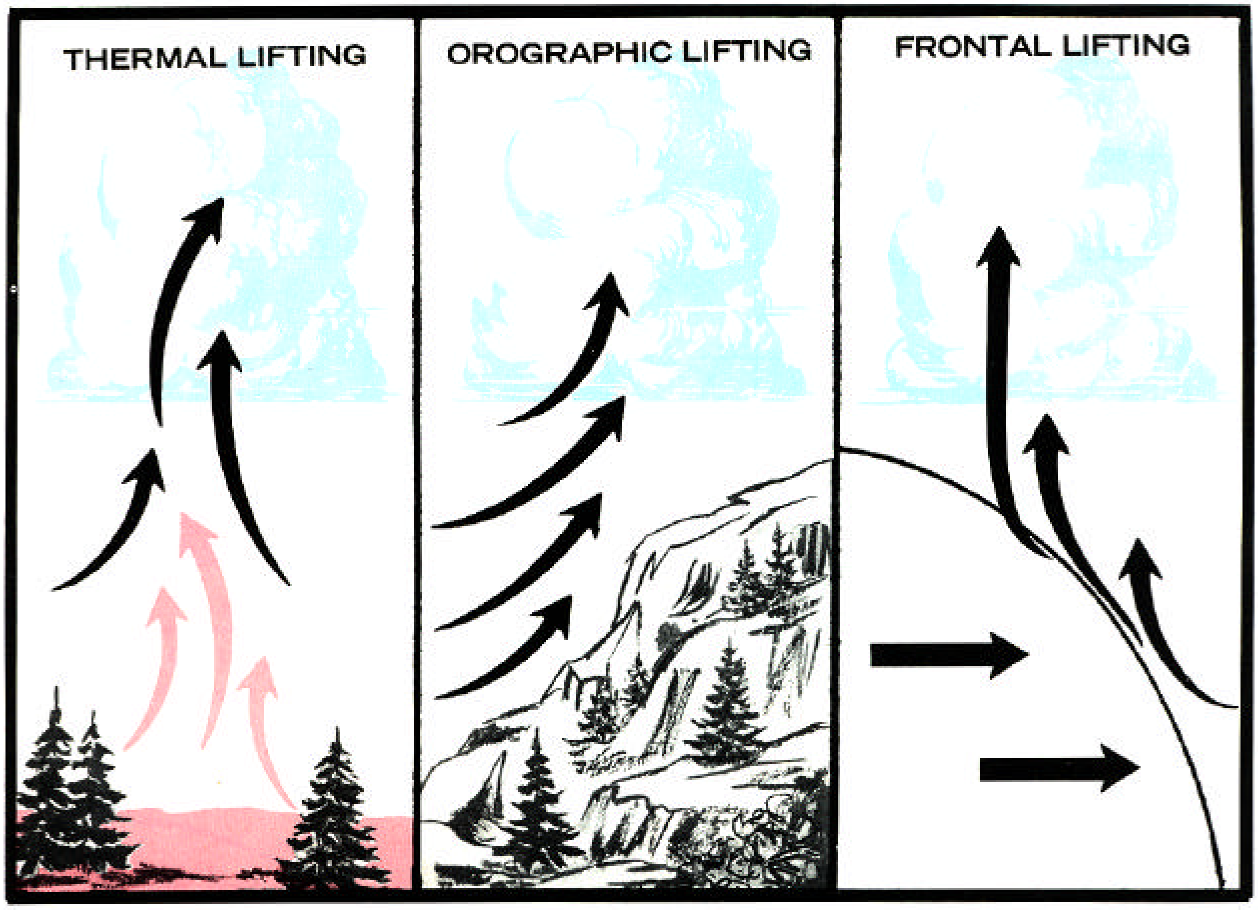
Local heating will result in thermal lifting. As heated surface air becomes buoyant, it is forced aloft and cools. The air cools at the dry-adiabatic rate of 5.5°F. per thousand feet, while the dew point lowers only about 1°F. per thousand feet, reflecting the decreasing absolute humidity with expansion. Thus the temperature



Moist air may be cooled to its dew point and become saturated as it passes over cool and or water surfaces. Nighttime cooling of the ground surface by radiation, and the subsequent cooling of adjacent moist air, may produce saturation and fog.



Air can become saturated by the addition of moisture. This may occur by evaporation as cold, dry air passes over warm water, or as warm rain from above a front foils through cold air beneath the front.



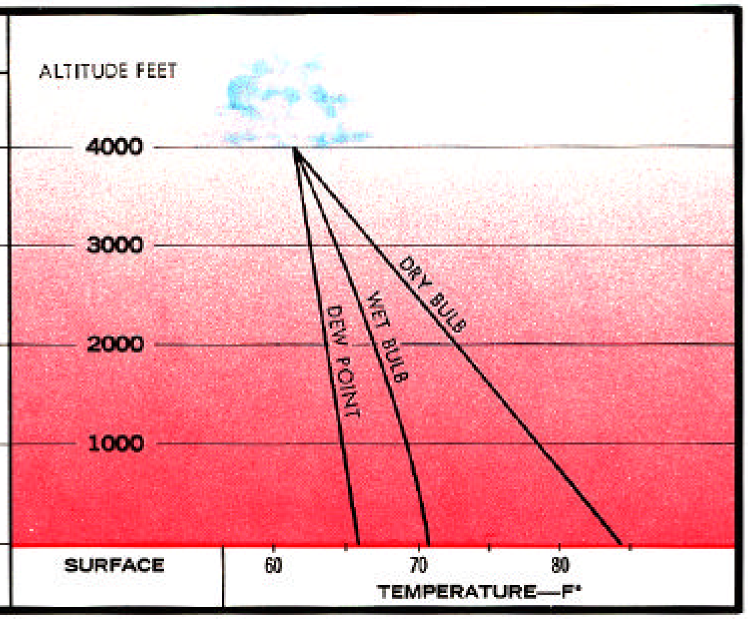
The most important method of cooling air to saturation is adiabatic cooling because of lifting. Lifting may be thermal, orographic, or frontal.

and dew point approach each other at the rate of 4.5°F. per thousand feet. If the locally heated air contains enough moisture and rises far enough, saturation will be reached and cumulus clouds will form. In fact, a common method of estimating the base of cumulus clouds formed, usually in the summer months, by thermal convection in the lower layers is to divide the difference between the surface air temperature and dew point by 4.5. This gives the approximate height of the cloud base in thousands of feet.

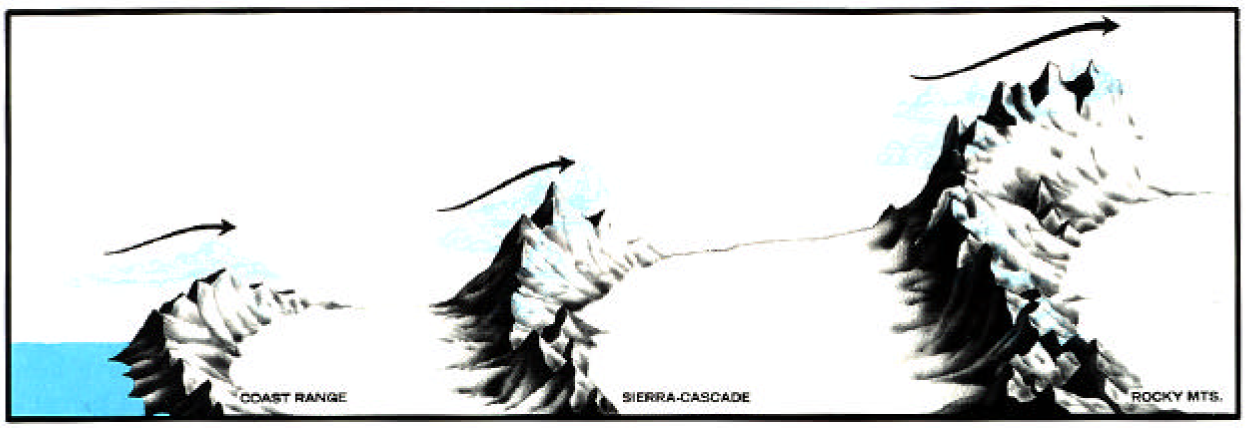
As an example, suppose we begin with heated air at the surface having a temperature of 84°F., wet-bulb temperature of 71°F., dew-point temperature of 66° F., and a relative humidity of 54 percent. If the air rose to an altitude of 4,000 feet, the dry-bulb, wet-bulb, and dew-point temperatures would all have decreased to 62°F. Saturation would have been reached as the humidity would be 100 percent. Continued rising would produce condensation and visible clouds.

Thermal lifting is most pronounced in the warm seasons. It may turn morning stratus clouds into stratocumulus with the possibility of light showers. More frequently, depending on stability, continued heating develops cumuli-form clouds that result in heavier showers and thunderstorms. Rainfall associated with thermal lifting is likely to be scattered in geographic extent. In flat country, the greatest convective activity is over the hottest surfaces. In mountain country, it is greatest over the highest peaks and ridges.

DRY BULB	WET BULB	DEW POINT	MOISTURE	REL. HUM.
°F	°F	°F	LB/M CU FT	
62.0	62.0	62.0	.85	100
67.5	64.2	63.0	.87	83
73.0	66.8	64.0	.89	72
78.5	69.0	65.0	.91	62
84.0	71.0	66.0	.94	54



If the temperature at the surface of a thermally lifted parcel of air was 84°F., the wet-bulb 71°F., and the dew point 66°F., saturation would b. reached at 4,000 feet above the surface.

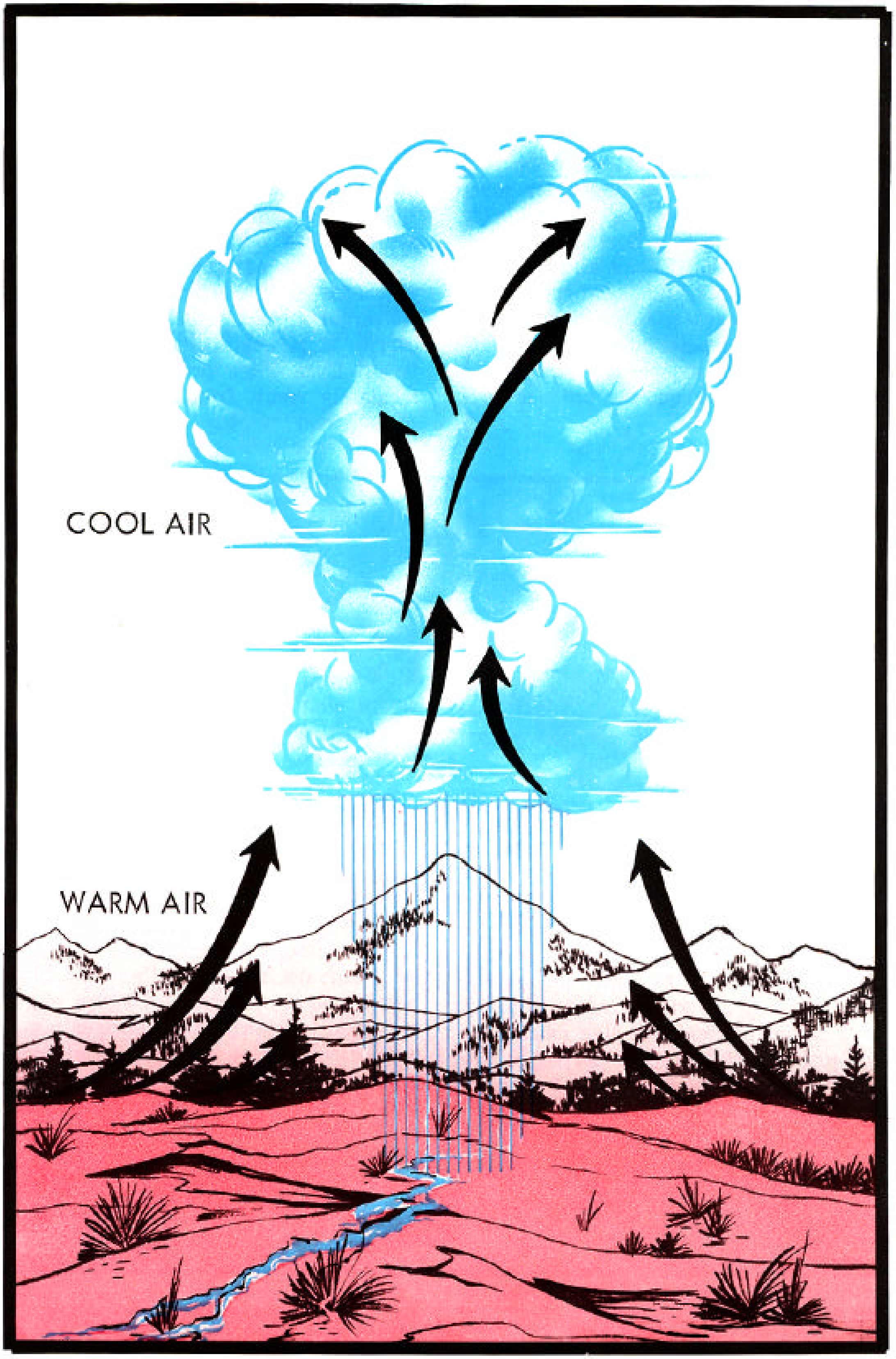


Lifting of moist air over mountain ranges is an important process in producing clouds and precipitation. In the West the winter precipitation is heaviest on the western slopes of the Coast Ranges, Sierra-Cascades, and Rocky Mountains. Lowlands to east of the ranges are comparatively dry.

Orographic lifting, in which air is forced up the windward side of slopes, hills, and mountain ranges, is an important process in producing clouds and precipitation. As in thermal lifting, the air is cooled by the adiabatic process.

In the West, maritime polar air flowing in from the Pacific Ocean produces winter clouds and precipitation as it is lifted over the mountain ranges. The Coast Ranges, Sierra-Cascades, and Rocky Mountains are the principal mountain systems involved. Lifting in each case occurs on the western slopes, and it is these that receive the heaviest precipitation. The lee slopes and adjacent valleys and plains receive progressively less as the air moves eastward.

Similarly in the East, maritime tropical air that has moved into the central portion of the United States and Southern Canada is lifted and produces precipitation in the Appalachian

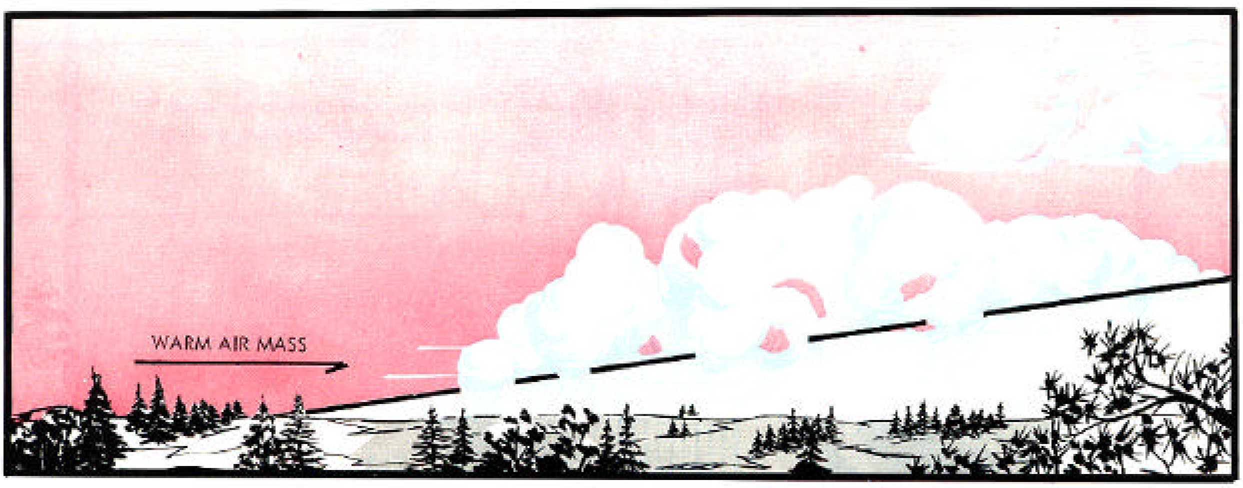


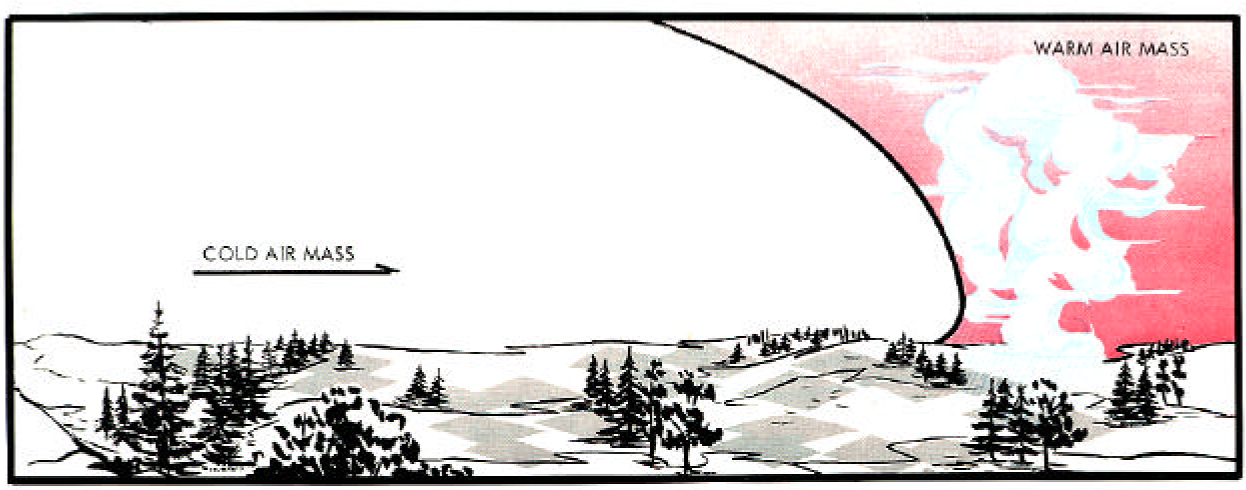
Thermal lifting usually produces cumulus clouds. Continued heating in moist air will result in showers and possibly thunderstorms.

Mountains as it progresses eastward. Other air masses, such as continental polar and maritime polar, will also cause precipitation in these mountains if they have acquired sufficient moisture before being lifted.

Frontal lifting, as air is forced up the slope of warm or cold fronts, accounts for much cloudiness and precipitation in all regions in the winter and in many regions during all seasons of the year. East of the Rockies and along the west coast, warm fronts, because of the gradual slope of their frontal surfaces, typically produce steady rains over extensive areas. Cold fronts, with characteristically steeper and faster moving leading surfaces, frequently produce more intense rainfall from cumulonimbus clouds along the front or along a squall line ahead of the front. This rainfall, however, is usually more scattered and of a shorter duration than that produced by a warm front.

Convergence is another important method of lifting which produces clouds and precipitation. During convergence, more air moves horizontally into an area that moves out. The excess is forced upward. Since moisture is concentrated in the lower atmospheric levels, convergence, like other lifting mechanisms, carries large quantities of moisture to higher levels. Even when precipitation does not immediately result from this cause, subsequent





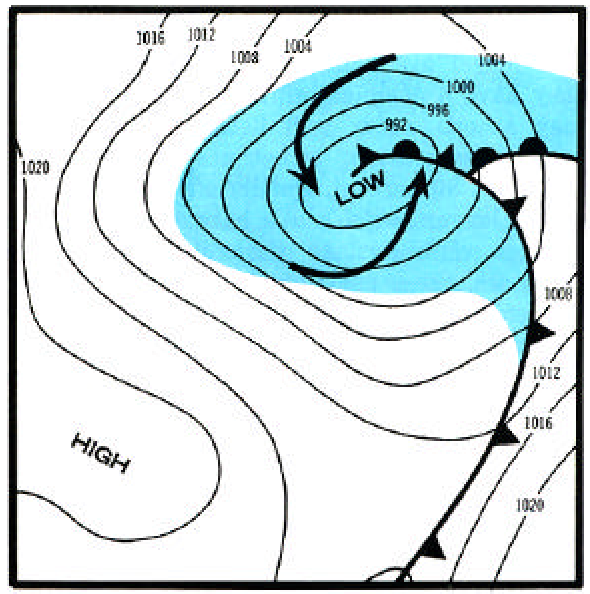
Top. - Lifting of warm, moist air, as it is forced up the slope of a warm front, produces widespread cloudiness and precipitation.

Bottom—The steepness and speed of cold fronts result in a narrow band of cloudiness and precipitation as warm, moist air ahead of the front is lifted.

precipitation triggered by other processes may be much more intense than if convergence had not occurred.

As we discussed in chapter 5, the circulation around a low-pressure system results in convergence. Here, friction deflects the flow toward the center. With more air flowing toward the center than away from it, there is a corresponding upward flow of air. For this reason, low-pressure areas are usually areas of cloudiness and precipitation. On a small scale, convergence occurs during the daytime over mountain peaks and ridges as thermal up-slope winds from opposing sides meet at the top.

We have discussed various methods by which air becomes saturated and condensation and precipitation are produced, but we must remember that in most cases two or more of these methods are acting at the same time. Daytime cumulus clouds over mountains may be produced by heating, orographic lifting, and the convergence of thermal winds all acting together. Nighttime fog and drizzle in maritime tropical (mT) air that moves from the Gulf of Mexico into the Plains regions may be the result of a combination of orographic lifting and nighttime cooling. Frontal lifting may be assisted by orographic lifting in mountain areas, or by convergence in low-pressure areas and troughs.



The circulation around a low-pressure area causes horizontal converging of air at low levels and lifting of air near the center. For this reason, low-pressure areas usually are areas of cloudiness and precipitation. Frontal lifting is frequently combined with convergence.

CONDENSATION, SUBLIMATION, AND PRECIPITATION PROCESSES

We discussed earlier in chapters 1 and 3 some of the aspects of condensation and sublimation. We were concerned with the change of state of water from gaseous to liquid or solid forms, and we used for simple examples the impaction of water vapor molecules on a liquid or solid surface. Dew and frost do form that way, but cloud particles are formed in the free atmosphere, and here the process becomes more complicated. Still more complex are the processes of precipitation where cloud particles must grow to a large enough size to fall out by gravity.

We are all familiar with condensation and sublimation. We have noticed the condensation of our breath on cold days, and of steam rising from boiling water. We have seen dew formed on grass at night, or on cold water pipes and cold glasses, and have noticed the sublimation of water vapor into frost on cold window panes in winter.

For condensation or sublimation to occur in the free air, a particle or nucleus must be present for water-vapor molecules to cling to. These fine particles are of two types: condensation nuclei and sublimation nuclei. Condensation nuclei, on which liquid cloud droplets form, consist of salt particles, droplets of sulfuric acid, and combustion products. They are usually abundant in the atmosphere so that cloud droplets form when saturation is reached. Sublimation nuclei, on which ice crystals form, consist of dust, volcanic ash, and other crystallline materials. Because of differences in composition and structure, different nuclei are effective at different below-freezing temperatures. As the temperature decreases, additional nuclei become active in the sublimation process. These nuclei are not as plentiful as condensation nuclei. Even at temperatures well below freezing, there frequently are too few effective nuclei to initiate more than a scattering of ice crystals.

The small particles that act as condensation nuclei are usually hygroscopic; that is, they have a chemical affinity for water. They may absorb water well before the humidity reaches saturation, sometimes at humidities as low as 80 percent. Condensation forms first on the larger nuclei, and a haze develops which reduces visibility. As the relative humidity increases, these particles take on more water and grow in size while condensation also begins on smaller nuclei. Near saturation, the particles have become large enough to be classed as fog or cloud droplets, averaging 1/2500— inch in diameter, and dense enough so that the mass becomes visible. Rapid cooling of the air, such as in strong upward currents, can produce humidities of over 100 percent—supersaturation—temporarily. Under such conditions droplets grow rapidly, very small nuclei become active and start to grow, and many thousands of droplets per cubic inch will form. With supersaturation even nonhygroscopic particles will serve as condensation nuclei, but usually there are sufficient hygroscopic nuclei so that the others do not have a chance.

As condensation proceeds, droplets continue to grow until they reach a maximum size of about 1/100 inch in diameter, the size of small drizzle drops. The condensation process is unable to produce larger droplets for several reasons. As vapor is used up in droplet formation, supersaturation decreases and the cloud approaches an equilibrium state at saturation. Also, as droplets grow, the mass of water vapor changing to liquid becomes large and the resultant latent heat released in the condensation process warms the droplet and decreases the vapor pressure difference between it and the surrounding vapor. Thus the vast majority of clouds do not produce rain. If growth to raindrop size is to take place, one or more of the precipitation processes must come into play. We will discuss these later.

An important phenomenon in the physics of condensation and precipitation is that liquid cloud droplets form and persist at temperatures well below freezing. Although ice melts at 32°F., water can be cooled much below this before it changes to ice. Liquid cloud droplets can exist at temperatures as low as —40°F. More commonly in the atmosphere though, cloud droplets remain liquid down to about 15°F. Liquid droplets below 32°F. are said to be supercooled. At temperatures above 32°F., clouds are composed only of liquid droplets. At temperatures much below 15°F. they are usually composed mostly of ice crystals, while at intermediate temperatures they may be made up of supercooled droplets, ice crystals, or both.

Why don’t ice crystals form more readily? First, the formation of ice crystals at temperatures higher than —40°F. requires sublimation nuclei. As was mentioned above, these usually are scarce in the atmosphere, especially at higher elevations. Also, many types of nuclei are effective only at temperatures considerably below freezing. But another reason why vapor condenses into liquid droplets, rather than sub-limes into ice crystals, is that condensation can begin at relative humidities well under 100 percent while sublimation requires at least saturation conditions and usually super-saturation.

Given the necessary conditions of below-freezing temperature, effective sublimation nuclei, and supersaturation, sublimation starts by direct transfer of water vapor to the solid phase on a sublimation nucleus. There is no haze phase as in the case of condensation. Once sublimation starts, ice crystals will grow freely under conditions of supersaturation. Since there are fewer sublimation than condensation nuclei available, the ice crystals that form grow to a greater size than water droplets and can fall from the base of the cloud.

Only very light snow, or rain if the crystals melt, can be produced by sublimation alone. Moderate or heavy precipitation requires one of the precipitation processes in addition to sublimation.

After condensation or sublimation processes have gone as far as they can, some additional process is necessary for droplets or crystals to grow to a size large enough to fall freely from the cloud and reach the ground as snow or rain. Cloud droplets, because of their small size and consequent slight pull of gravity, have a negligible rate of fall, and for all practical purposes are suspended in the air. Even drizzle droplets seem to float in the air. Raindrops range in size from about 1/50 inch to 1/5 inch in diameter. Drops larger than 1/5 inch tend to break up when they fall. It takes about 30 million cloud droplets of average size to make one raindrop about 1/8 inch in diameter.

There seem to be two processes which act together or separately to cause millions of cloud droplets to grow into a raindrop. One is the ice-crystal process and the other is the coalescence process.

The Ice-Crystal Process

We have seen that ice crystals and cloud droplets can coexist in clouds with subfreezing temperatures. For the ice-crystal process of precipitation to take place, clouds must be composed of both ice crystals and supercooleci liquid cloud droplets.

In chapter 3 we discussed vapor pressure and saturation vapor pressure at some length, but we considered only saturation vapor pressure with respect to liquid water. The saturation vapor pressure with respect to ice is somewhat less than that with respect to super-cooled water at the same temperature, as shown in the following table:

Comparative Saturation Vapor Pressures
Over Water and Ice

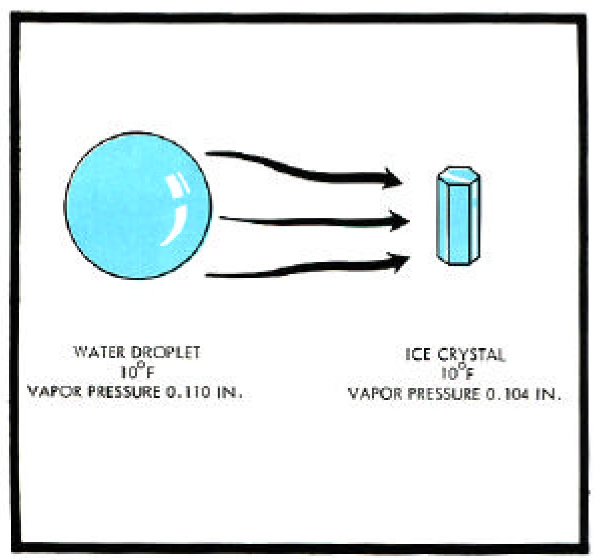
Tempera-ture	Saturation vapor	pressure	Relative humidity over ice
	Over water	Over ice	
(°F.)	(Inches of	mercury)	(Percent)
0	0.045	0.038	119
10	.U71	.063	112
20	.110	.104	106
30	.166	.164	101

If a cloud containing supercooled water droplets is saturated with respect to water, then it is supersaturated with respect to ice, and the relative humidity with respect to ice is greater than 100 percent. The force resulting from the difference between vapor pressure over water and over ice causes vapor molecules to be attracted to ice crystals, and the ice crystals will grow rapidly. As the ice crystals gather up vapor molecules in the cloud, the relative humidity with respect to water drops below 100 percent, and liquid cloud droplets begin to evaporate. Vapor molecules move to the ice crystals and crystallize there. Thus, the ice crystals grow at the expense of the water droplets and may attain a size large enough to fall out of the cloud as snowflakes. If the snowflakes reach warmer levels, they melt and become raindrops, This is the ice-crystal precipitation process.

Artificial Nucleation

The knowledge that frequently there is a scarcity of sublimation nuclei and ice crystals in supercooled clouds has led to the discovery that precipitation can be initiated artificially. It has been found that silver-iodide crystals, which have a structure similar to ice crystals, can be effective sublimation nuclei in super-cooled clouds at temperatures below about 20°F. Silver-iodide crystals can be released in the cloud by aircraft or rockets, or carried to the cloud by convection from ground generators.

Ice crystals can be created in a supercooled ('loud by dropping pellets of dry ice, solid carbon dioxide, into the cloud from above. The dry ice, which has a melting temperature of -108°F., cools droplets along its path to temperature



In the ice-crystal precipitation process, ice crystals grow at the expense of water droplets. Because of the difference in vapor pressure over ice and over water at the same temperature, a vapor-pressure gradient exists between supercooled water droplets and ice crystals in mixed clouds. Vapor molecules leave the water droplets and sublime on the ice crystals.

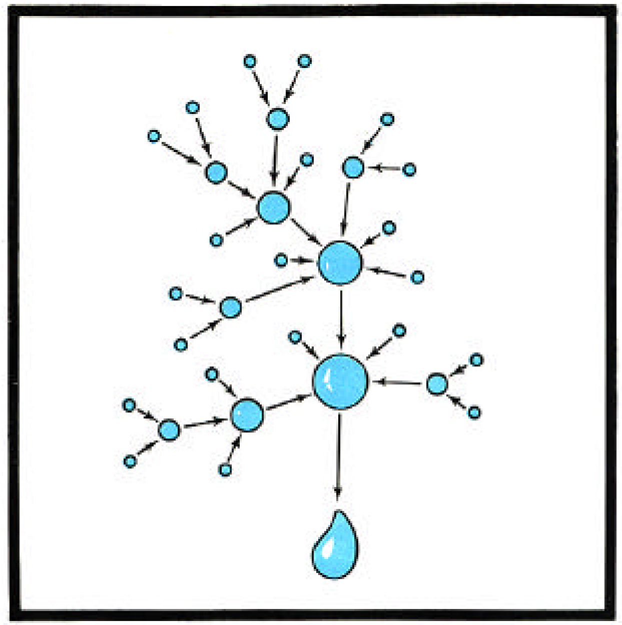
lower than —40°F. so that they can freeze into ice crystals without the presence of sublimation nuclei. Once crystals are produced, they act as nucleating particles themselves and affect other parts of the cloud.

Once formed in a supercooled water cloud, ice crystals may grow by the ice-crystal process and coalescence processes until they are large enough to precipitate. Studies have provided evidence that the artificial nucleation of super-cooled clouds can, under the proper conditions, increase local precipitation significantly.

Coalescence

Since rain also falls from clouds which are entirely above freezing, there must be a second precipitation process. This is a simple process in which cloud droplets collide and fuse together, or coalesce. Clouds which produce precipitation are composed of cloud droplets of varying sizes. Because of the different sizes, cloud droplets move about at different speeds. As they collide, some of them stick together to form larger drops. The larger cloud droplets grow at the expense of smaller ones, and actually become more effective in the collecting process as they become larger. As larger drops begin to fall, they tend to sweep out the smaller drops ahead of them.

The coalescence process takes place in clouds of both above-freezing and below-freezing temperatures. Snowflakes coalesce with other snowflakes as they fall to form the large clumps which we sometimes observe. They may also coalesce with supercooled water droplets to form snow pellets.



In the coalescence process of precipitation, small droplets collide and fuse together to become larger droplets. The process continues until enough droplets are accumulated into large drops so that the large drops fall because of gravity. Snowflakes coalesce into snowflake masses in a similar manner.

KINDS OF CLOUDS

In order to recognize and identify clouds it is necessary to classify and name them. Clouds are identified by their development, content and appearance, and their altitude. They are classified into many types and subtypes, but we need be concerned only with the more basic types. We will consider four families of clouds distinguished by their height of occurrence:

High clouds, middle clouds, low clouds, and clouds with vertical development.

Within the first three families are two main subdivisions:

1. Clouds formed by localized vertical currents which carry moist air upward beyond the condensation level. These are known as cumuliform clouds and have a billowy or heaped-up appearance.

2. Clouds formed by the lifting of entire layers of air, without strong, local vertical currents, until condensation is reached. These clouds are spread out in layers or sheets and are called stratiform.

In addition, the word nimbus is used as a prefix or suffix to indicate clouds producing precipitation—resulting in such names as nimbostratus or cumulonimbus. The word fractus is used to identify clouds broken into fragments by strong winds—such as stratus fractus and cumulus fractus.

Air stability has an important effect on the type of cloud formation. A stable layer which remains stable through forced lifting will develop stratiform clouds. Cumuliform clouds develop in air that is initially unstable or becomes unstable when it is lifted. A layer of conditionally unstable air which is forced to ascend may first develop stratiform clouds and then develop cumuliform clouds as the layer becomes unstable. The cumuliform clouds project upward from a stratiform cloud layer. Thus, the type of cloud formation can be used as an indicator of the stability of the atmospheric layer in which the clouds are formed.

High Clouds

High clouds have bases ranging from 16,500 to 45,000 feet. Cirrus, cirrocumulus, and cirrostratus clouds are included in this family. They are usually composed entirely of ice crystals, and this is their most distinguishing characteristic.

Cirrus are isolated wisps of thin, feathery cloud up near the top of the troposphere. They are sometimes called “mares’ tails” and may have trailing streams of larger ice crystals beneath them.

Cirrocumulus clouds consist of patches of small, white cloud elements. They may form definite patterns at times, showing small but firm waves or ripples. They are sometimes referred to as “mackerel sky.” True cirrocumulus are rare and are associated with other forms of typical cirrus at the same level, often changing into other forms of cirrus in a short time.

Cirrostratus clouds are thin, whitish veils, sometimes covering the entire sky. Halos around the sun or moon, caused by their ice-crystal composition, frequently identify this cloud type.

Cirrus clouds are thin, white, feathery clouds in patches or narrow bands. They are composed of ice crystals of varying size. Larger crystals often trail down vertically and have given rise to the name “mares’ tails.”

Cirrocumulus clouds contain small, white individual puffs. They may contain some supercooled water droplets mixed in with the ice crystals. Cirrocumulus is rare and is sometimes called "mackerel sky."

Cirrostratus is a thin, whitish, transparent cloud layer appearing as a sheet or veil, It generally produces a halo around the sun or moon.

Cirrus-type clouds may be produced in several ways. Often they are the forerunner of warm-front activity and give advance warning. Sometimes they are associated with the jet stream and usually are found on the south side of the jet. They may also be produced from the anvil tops of thunderstorms. The value of cirrus clouds in fire weather is their advance warning of warm-front activity and their use in indicating high-altitude moisture and wind direction and speed.

Middle Clouds

Middle clouds have bases ranging from 6,500 feet up to 20,000 feet. Altocumulus and altostratus clouds fall into this group. Middle clouds are most generally formed by either frontal or orographic lifting, but may be formed in other ways. Often they are associated with lifting by convergence in upper-air troughs and sometimes develop with thunderstorms.

Altocumulus are white or gray patches, with each individual component having a rounded appearance. Altocumulus may appear as irregular cloudlets or in definite patterns such as bands or rows parallel or at right angles to the wind. Usually, the stronger the wind, the more distinct the pattern. Altocumulus are usually composed of water droplets and often are supercooled.

Altostratus appears as a gray or bluish layer or veil with a sort of fibrous texture. It may be made up of supercooled water droplets or a mixture of water droplets and ice crystals. It tends to cover the entire sky, and the sun will shine through dimly as through a frosted glass.

Altocumulus are white or gray patches or rolls of solid cloud. They are distinguished from cirrocumulus by the larger size of the cloud elements. Altocumulus clouds are usually composed of water droplets, often supercooled, but may contain some ice crystals at very low temperatures.

As altostratus becomes thicker and lower, the sun becomes obscured. If it becomes dense and low enough, it becomes nimbostratus and takes on a wet and rainy appearance due to widespread precipitation. If the precipitation evaporates before reaching the ground, it is called virga.

Three special types of middle clouds are of considerable importance in identifying weather conditions. The lens-shaped lenticular cloud appears over the ridge and to the lee of mountain ranges. Lenticular clouds indicate waves in the air flow caused by strong winds blowing across the range. The clouds form in the rising current on the upwind side of the wave crest and dissipate in the downward flow on the other side.

The castellanus type of cloud consists of cumuliform masses in the form of turrets, usually arranged in lines. They indicate marked instability at high levels, and their occurrence in the forenoon is a warning of possible thunderstorm activity in the afternoon.

Clouds with rounded lower surfaces in the form of pouches or udders are called mamma. They are most common on the underside of cumulonimbus anvils. The pendulous blobs of cloud are sinking into the clear air immediately below because they contain droplets and ice crystals. As the droplets and crystals evaporate, they chill the air in the pendants. By this chilling, they keep the air denser than the surrounding clear air. The process ends when all

Altostratus appears as a gray or bluish layer having a fibrous appearance, often associated with altocumulus. Frequently, it is composed of a mixture of supercooled water droplets and ice crystals. Light rain or snow often falls from it.

Nimbostratus is a gray or dark massive cloud layer diffused by more-or-less continuous rain or snow which usually reaches the ground. It is thick enough to blot out the sun. Lower ragged clouds often appear beneath the nimbostratus layer.

cloud particles have evaporated. Pilots have reported that the downdrafts within mamma are quite weak. However, any adjacent thunderstorms will have zones of marked turbulence.

Low Clouds

The bases of low clouds range from the surface to 6,500 feet. Low clouds include stratus, stratocumulus, and nimbostratus.

Nimbostratus clouds form a gray, often dark, layer usually accompanied by continuously falling rain or snow. The precipitation usually reaches the ground, but occasionally only virga appears. Nimbostratus usually develops from thickening and lowering alto-stratus. Stratus fractus or scud clouds often appear beneath the nimbostratus layer.

Stratus and stratocumulus are very common and widespread. They usually occur beneath an inversion and are fairly thin, ranging from a few hundred to a few thousand feet thick. Stratus forms a low, uniform sheet, dull gray in appearance. It is composed of water droplets and does not produce rain, although it may produce drizzle. Fog is simply a stratus cloud lying on the surface. When a fog layer lifts, as it frequently does during the forenoon, it becomes a stratus layer. In some localities, particularly the west coast, stratus is referred to as high fog.

Fog is important in fire weather because of its effect on the moisture content of forest fuels. While fog is forming or persisting, conditions are favorable for fuels to absorb moisture. Fog occurs during calm or light-wind

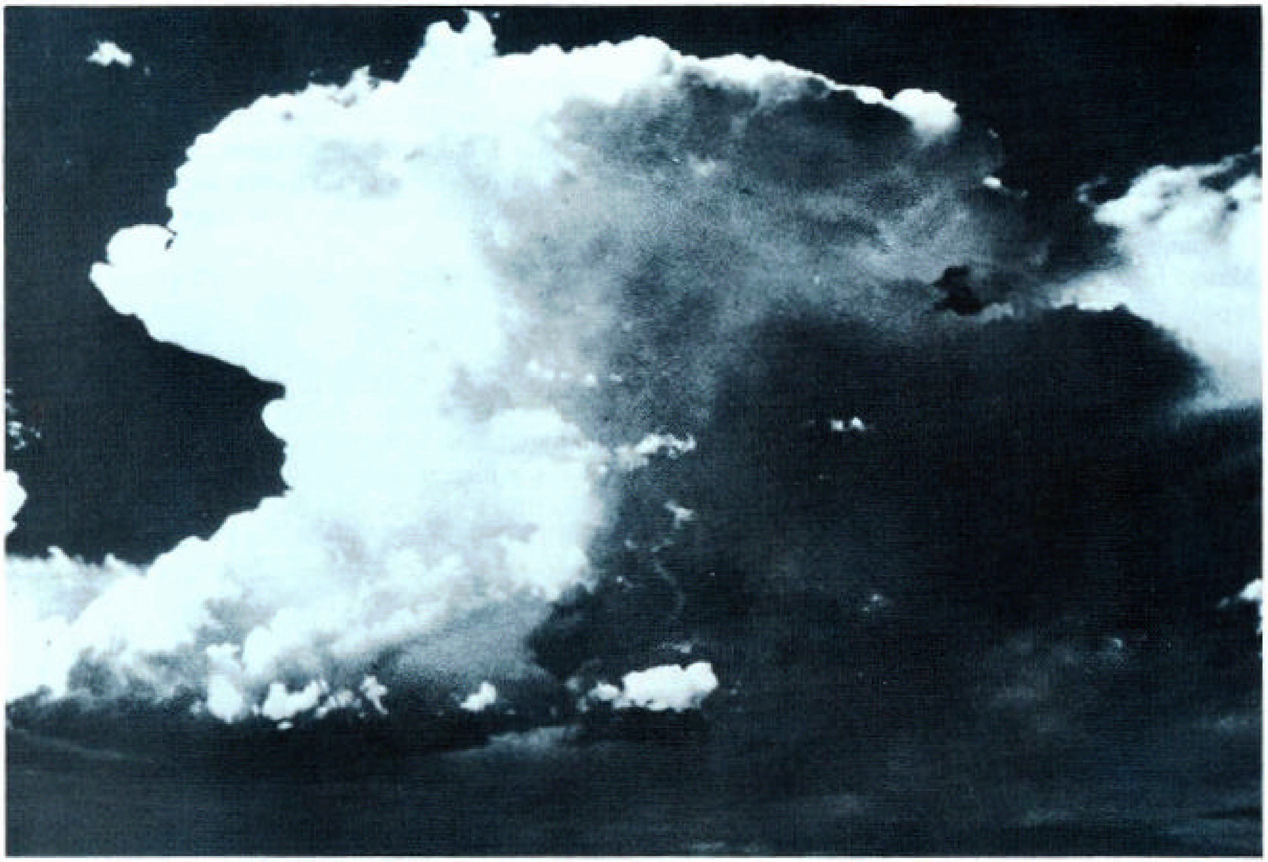
Stratus is a low, gray cloud layer with a fairly uniform base and top. Usually it does not produce precipitation, although it may cause some drizzle or snow grains. Stratus often forms by the lifting of a layer of fog.

Stratocumulus clouds consist of gray or bluish patches or layers with individual tolls or rounded masses. They are generally composed of small water droplets and may produce light drizzle, conditions in a stable atmosphere and is formed in several ways. Radiation fog is formed when moist air cools to its dew point at night over a strongly radiating surface. Some vertical mixing is necessary to produce a layer of fog of significant thickness. Advection fog forms when warm, moist air passes over a cool surface and its temperature is reduced to the dew point. Many fogs are a combination of these two types. Upslope fog forms when moist, stable air is forced to rise along a sloping land surface. This type occurs especially along the western edge of the Great Plains when mT air moves northwestward from the Gulf of Mexico. Fog may also occur in connection with fronts, particularly in advance of warm fronts where evaporating rain falling through a layer of cold air near the surface saturates the cold air.

The distinction between stratus and strato-cumulus is not particularly important. Strato-cumulus shows individual rolls or rounded masses, usually soft and gray. It forms when the air is somewhat unstable, whereas stratus forms in stable air. Like stratus, it is composed of small water droplets and may produce light drizzle.

Clouds with vertical development include cumulus and cumulonimbus. These are irregularly shaped masses with domes or turrets and have a cauliflower appearance. They usually appear in groups, and individual cloud bases are at about the same altitude. The height of the bases, which is the condensation level described in chapter 4, depends upon the air temperature and the amount of moisture in the atmosphere. Cumulus clouds are formed near the top of rising convection columns, and their bases may

Cumulus clouds are detached clouds in the form of rising mounds or domes. They are dense, have sharp outlines, and the upper portion often resembles a cauliflower. They are composed of a great density of small water droplets; ice crystals may appear in the tops of larger cumulus.



Cumulonimbus clouds are heavy and dense with considerable vertical development sometimes reaching the tropopause. The top often takes on the shape of an anvil. Cumulonimbus, often abbreviated to "cb," is frequently accompanied by lightning and thunder, rain, sometimes hail, and on occasion a tornado or waterspout.

range in height from a few thousand feet to 15,000 feet or more. Their presence is of special interest in fire weather as an alert to possible convection in the surface layer. They are a common type during the fire season, particularly in mountainous regions.

The most common type of cumulus is a small, puffy type occurring during fair weather, called cumulus humili or fair weather cumulus. They appear after local surface heating becomes sufficiently intense to support convection, and dissipate in the late afternoon as surface heating decreases and convection ceases. These clouds have relatively flat bases, rounded or cone-shaped tops, and are usually isolated or in small groups. Their vertical growth is usually restricted by a temperature inversion which makes the tops fairly uniform. Occasionally a single cloud element will develop vertically to some height. True fair-weather cumulus clouds, however, remain flat, but their presence indicates local updrafts that may influence fire behavior.

The danger from cumulus clouds is more acute, however, if the air is sufficiently moist and unstable to support their growth into towering cumulus. Virga or rain sometimes falls from the base of large cumulus.

The final stage of cumulus development is the cumulonimbus or thunderhead, which is characterized by a flat anvillike formation at the top. The stretched-out shape of the anvil indicates the direction of air motion at that level. The anvil top is composed of sheets or veils of ice crystals of fibrous appearance which are sometimes blown off to form cirrus-type clouds. Dissipating anvils give the appearance of dense cirrus and are sometimes referred to as false cirrus.

The greater the vertical development of cumulonimbus, the more severe the thunderstorm. Tops of cumulonimbus may extend to altitudes of 60,000 feet or higher and often reach the tropopause. Rain or snow showers usually accompany cumulonimbus clouds, and thunder, lightning, and hail are common.

Cumulus and cumulonimbus clouds not associated with frontal or orographic lifting indicate strong surface heating and atmospheric instability from the surface up through the level of the cloud tops. Surface winds are likely to be gusty and increase in speed as the cumulus forms. Other convection phenomena such as dust devils, whirlwinds, and considerable turbulence may be present. In addition to lightning, strong cold downdrafts present a threat from well developed thunderheads. Because of the importance of thunderstorms in fire weather, we will discuss them in detail in the following chapter.

Cumulus cloud caps often form atop the convection columns over large forest fires. Their moisture source may be almost entirely water vapor from the combustion process, or it may be water vapor entrained with air through which the column rises. Such clouds occasionally produce showers, but this is quite rare.

KINDS OF PRECIPITATION

Precipitation products can be divided into three basic classes depending on their physical characteristics when they strike the earth:
Liquid, freezing, and frozen.

Rain and drizzle are the two kinds of liquid precipitation. The difference is mainly one of size and quantity of droplets. Drizzle droplets range in size from about 1/500 to 1/50 inch. Drizzle is formed in, and falls from, stratus clouds, and is frequently accompanied by fog and low visibility. Raindrops range in size from about 1/100 to 1/4 inch. They are much more sparse than drizzle droplets. Rain may come from liquid droplets formed by the coalescence process in warm clouds, or from melted snowflakes originally formed in cold clouds by both the ice crystal and coalescence processes. The snowflakes melt when they reach air with above-freezing temperatures. Rainfall intensity may vary from a few drops per hour to several inches in a matter of minutes. Heavier rainfall usually consists of larger drops.

Freezing rain and freezing drizzle are formed and fall as liquid drops that freeze on striking the ground. The drops may be above-freezing, but usually they are supercooled and freeze upon striking the ground or other cold objects. This occurs usually with warm-front rain formed in the warm air above the frontal surface, and then supercooled as it falls through the cold air beneath the front. The temperature at the ground must be lower than 32°F.

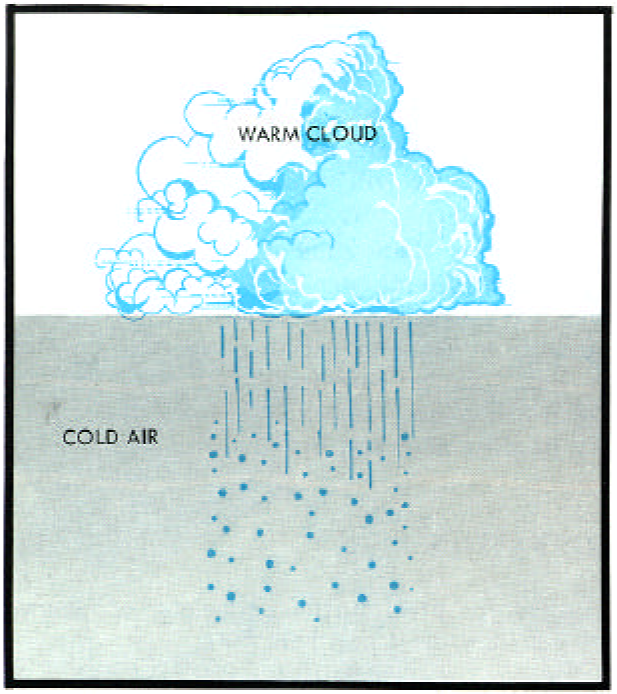
Frozen precipitation consists of snow, snow pellets, sleet and hail.

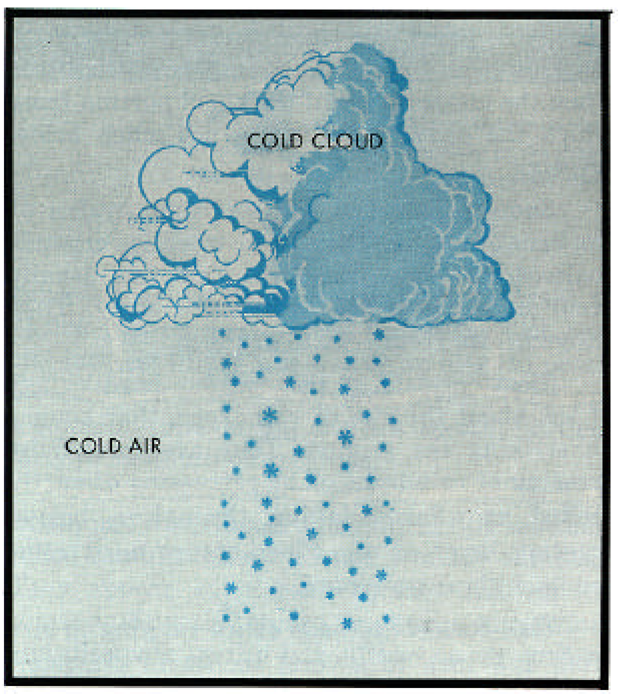
Snow consists of crystals of ice formed in pure ice clouds or in mixed clouds. The larger snowflakes are built up by the coalescence process. Air beneath the cloud must be near or below freezing, or the snow will melt before reaching the ground. The heaviest snowfalls occur when the temperature of the cloud portion from which the snow is falling is not much below freezing.

Snow pellets are white opaque grains of ice, usually round. They form when ice crystals coalesce with supercooled droplets, and usually occur in showers before or with snow. They range in size from 1/16 to 1/4 inch.

Sleet consists of transparent hard pellets of ice, about the size of raindrops, that bounce on striking the ground. They are formed by freezing of raindrops or by refreezing of partly melted snowflakes falling through a below-freezing layer of air. Sleet occurs most commonly with warm fronts.

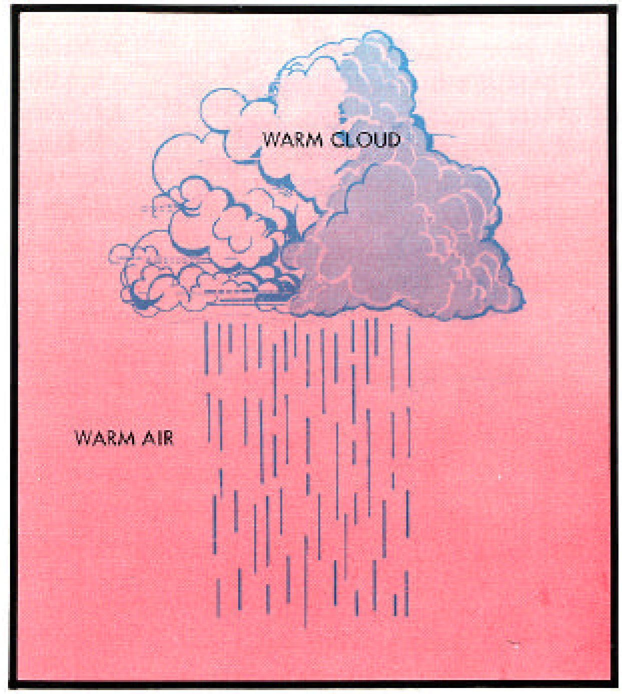
Hail consists of balls of ice ranging in size from 1/5 inch to several inches in diameter. They have layerlike structures indicating that they have grown by successive steps. Hailstones apparently begin their growth when supercooled water droplets impinge on ice pellets. The liquid water freezes on the ice pellet to form a layer of ice. This process is repeated until the hailstone falls out of the cloud. The repetition

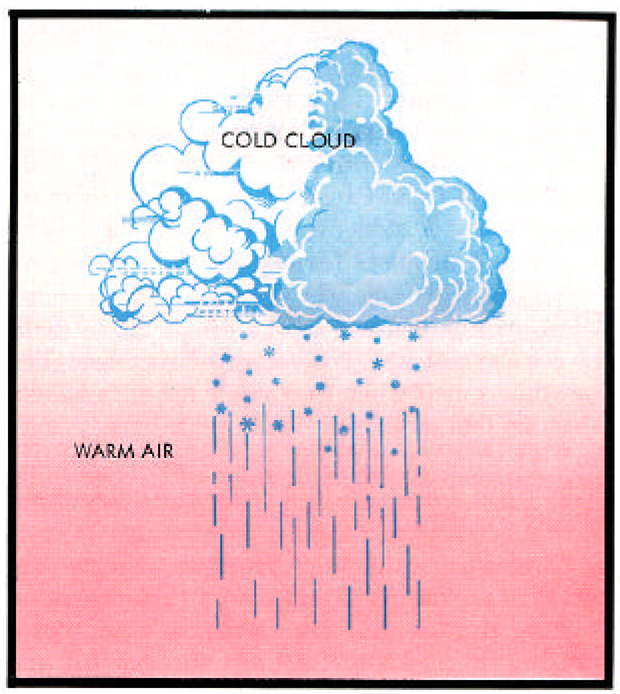




Top.— Sleet is formed by the freezing of liquid raindrops or the refreezing of partly melted snowflakes as they fall through a below-freezing layer of air.

Bottom.— Snow consists of crystals of ice formed in pure ice clouds or in mixed clouds, built up by the coalescence process and falling to the ground through cold air so that the flakes do not melt.





Top—Rain arriving at the ground may begin as liquid drops, formed by the coalescence process in warm clouds, which then fall to the ground through warm air.

Bottom.—Or rain may begin as snowflakes formed by the ice crystal and coalescence processes in cold clouds. The snowflakes subsequently melt as they fall through warm air.

may be due to the hailstone being caught in strong updrafts and carried upward into the region of supercooled droplets. It is also possible for the process to begin at very high altitudes, in which case the hailstone grows as it falls through successive concentrations of supercooled water. Hail is associated with thunderstorms and very unstable air.

There are two other forms in which moisture from the atmosphere is deposited on the ground. These are dew and frost. Dew and frost do not fall, but instead are deposited when water vapor condenses or sublimes on the ground or on objects near the ground. Dew forms when air next to the ground or to cold objects is chilled to the dew point of the air, but remains above freezing. A common example is the deposit of water that forms on a glass of ice water. Frost forms by sublimation when the air is chilled to its dew point and the dew point is below freezing. Dew and frost forming on forest fuels at night can add considerably to the fuel moisture.

MEASUREMENT OF PRECIPITATION

Precipitation is measured on the basis of the vertical depth of the water or melted snow. Snow, sleet, hail, and other solid forms are also measured on the basis of the depth of the unmelted form. Our common unit of measurement is the inch.

The standard rain gage is an 8-inch cylindrical container with an 8-inch funnel at the top and a measuring tube inside. The cross-sectional area of the measuring tube is exactly one-tenth that of the funnel top. Thus, if 0.01 of an inch of precipitation falls, it is 0.1 inch deep in the measuring tube. The stick used to measure the precipitation is graduated in inches, tenths, and hundredths, so that 0.01 inch of rain is indicated for each 0.1 inch of stick length. When snow is measured, the funnel and measuring tube are removed, and only the outside cylindrical container is used. Snow caught in the gage is melted and measured in the measuring tube to obtain the liquid equivalent of the snow.

Several types of recording gages that make continuous records of the precipitation are also in use. The tipping bucket gage can be used only for rain. For each 0.01 inch of rain, an electrical impulse is recorded. Another type is the weighing-type gage which can be used for either snow or rain. This device simply weighs the snow or rain that is collected. The weight is recorded continuously in inches of water on a chart attached to a revolving drum.

The rain gage should be exposed in the open away from large buildings or trees. Low bushes, fences, and walls are not objectionable, provided that the gage is placed at a distance of at least twice the height of the object. The top of the gage should be level.

SUMMARY

In this chapter we have learned that air becomes saturated either by the addition of moisture, or, more commonly, by cooling to the dew point. In saturated air, clouds form by the condensation of water vapor, which takes place on fine particles called condensation or sublimation nuclei.

Cloud droplets grow to sizes large enough to precipitate by the ice-crystal process, in which water vapor is transferred from evaporating, supercooled liquid droplets to ice crystals where sublimation takes place, or by coalescence of droplets or ice crystals into raindrops or clumps of snowflakes. Precipitation falls in the form of liquid rain or drizzle, freezing rain or drizzle, or frozen snow, sleet, or hail.

Clouds are classified according to their structure as stratus or cumulus, and according to their altitude as high, middle, low clouds, and those with large vertical development. In the last group are cumulonimbus or thunderstorm clouds. The weather associated with the thunderstorm has such serious effects on fire weather that the entire next chapter will be devoted to it.